Effect of Inductive Coil Geometry on the Thrust Efficiency of a Microwave Assisted Discharge Inductive Plasma Accelerator

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I. INTRODUCTION

Pulsed inductive plasma thrusters [1–3] are spacecraft propulsion devices in which electrical energy is capacitively stored and then discharged through an inductive coil. The thruster is electrodeless, with a time-varying current in the coil interacting with a plasma covering the face of the coil to induce a plasma current. Propellant is accelerated and expelled at a high exhaust velocity ($\mathcal{O}(10-100$ km/s)) by the Lorentz body force arising from the interaction of the magnetic field and the induced plasma current.

While this class of thruster mitigates the life-limiting issues associated with electrode erosion, pulsed inductive plasma thrusters require high pulse energies to inductively ionize propellant. The Microwave Assisted Discharge Inductive Plasma Accelerator (MAD-IPA) [4, 5] is a pulsed inductive plasma thruster that addressees this issue by partially ionizing propellant inside a conical inductive coil via an electron cyclotron resonance (ECR) discharge. The ECR plasma is produced using microwaves and permanent magnets that are arranged to create a thin resonance region along the inner surface of the coil, restricting plasma formation, and in turn current sheet formation, to a region where the magnetic coupling between the plasma and the inductive coil is high.

The use of a conical theta-pinch coil is under investigation. The conical geometry serves to provide neutral propellant containment and plasma plume focusing that is improved relative to the more common planar geometry of the Pulsed Inductive Thruster (PIT) [2, 3], however a conical coil imparts a direct radial acceleration of the current sheet that serves to rapidly decouple the propellant from the coil, limiting the direct axial electromagnetic acceleration in favor of an indirect acceleration mechanism that requires significant heating of the propellant within the volume bounded by the current sheet.

In this paper, we describe thrust stand measurements performed to characterize the performance (specific impulse, thrust efficiency) of the MAD-IPA thruster. Impulse data are obtained at various pulse energies, mass flow rates and inductive coil geometries. Dependencies on these experimental parameters are discussed in the context of the current sheet formation and electromagnetic plasma acceleration processes.

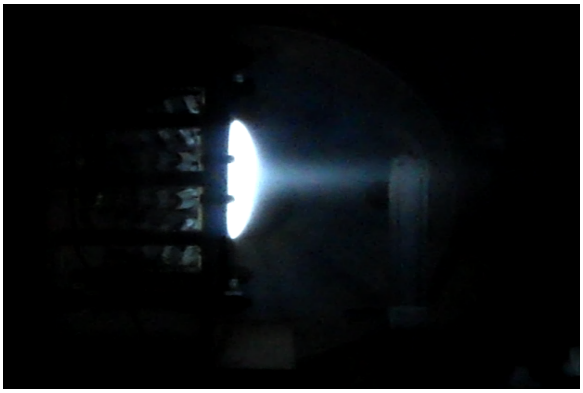

FIG. 1: Side view of the preionization stage of the Microwave Assisted Discharge Inductive Plasma Accelerator. The thrust axis points to the right.

II. EXPERIMENT AND RESULTS

All tests are performed in a stainless steel cylindrical vacuum facility 25-ft. long with a 9-ft. diameter. A base pressure of 5.7 x 10^{-7} torr is maintained by two 2400 l/s turbopumps and two 9500 l/s cryopumps. The MAD-IPA is mounted onto the VAHPER thrust stand, which is capable of supporting thrusters with masses up to 125 kg that produce between 100 μN and 1 N of steady-state thrust. The stand has been modified to support pulsed thrust measurements. More general information about the thrust stand can be found in Ref. [6].

Instead of injecting propellant into the MAD-IPA in discrete increments, neutral gas flows continuously into the thruster to replace propellant accelerated by the previous pulse. This allows sustainment of the ECR discharge, and in turn, repetition-rate discharging of the capacitor bank.

Impulse data were obtained at a variety of pulse energies ranging from 50 to 300 J, a range of propellant mass flow rates and propellant species, and for three different half cone angles (12, 20, and 38 degrees). It is

found that higher impulses are obtained for larger cone angles. This can be explained in light of the loss in potential direct electromagnetic axial acceleration as the current sheet compresses radially from the driving coil. Larger cone angles exhibit less decoupling for the same radial compression in addition to imparting a larger fraction of directed axial acceleration and therefore a smaller fraction of radial acceleration. Directed axial electromagnetic acceleration appears to be a more efficient thrust production mechanism in thrusters of this type that do not have a means of increasing the pressure of the propellant within the volume bounded by the current sheet.

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